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Self-organized InGaAs/GaAs quantum wire nanostructures grown by metal-organic vapor phase epitaxy

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Abstract. We report on observation of a new type of InGaAs self-assembled surface nanostructures grown on (001) GaAs by Metal-Organic Vapor Phase Epitaxy. Atomic Force Microscopy (AFM) studies show presence of a homogeneous system of well ordered shaped rectangular nanoislands extended along the [$\bar{1}$10] direction. Optical properties of the structures studied by photoluminescence (PL) and photoconductivity (PC) spectroscopy indicate presence of 1D electronic states.

Recently a lot of effort was devoted to study of the zero-dimensional semiconductor nanostructures (Quantum Dots, QDs) [1]. The most interest is attracted by the QDs obtained by self-assembling during the epitaxial process. The main advantage of this technique compared to other methods of QDs' preparation (for instance, nanolithography, selective growth, etc.) is that formation of the QDs by self-assembling is a natural process (usually driven by Stranski–Krastanov (S-K) mechanism [2]), and therefore is very promising for commercial device application. However, while for the QDs S-K self organization is well studied and is being used for growth of various 0D structures widely, in the field of using self-organization for formation of quantum wires there is much less success.

In [3] we reported on observation of self-assembled GaAsSb/GaAs quantum wires grown by AP-MOVPE. Here we report on AP-MOCVD growth and characterization of similar structures in InGaAs/GaAs system.

The structures were grown on semi insulating (001) GaAs misoriented by 3.1^o degrees towards [110] direction using trimethylgallium (TMG), trimethylindium (TMI) and arsine as the precursors. The structures were consisting of the 3 layers: a 0.3 μm buffer layer grown at 600 °C, an InAs layer grown at 530 °C, and a 40 nm cap layer. The InAs layer was grown in the altering submonolayer deposition mode switching TMI and arsine flow on for 6 and 2 seconds respectively with a 4 sec pause between each cycle; total 5 cycles.

The surface topography of the structures was characterized by ambient air Atomic Force Microscopy (AFM) on TopoMetrix TMX-2100 Accurex AFM in contact mode. The optical properties were studied by photoluminescence (PL) and by planar photoconductivity (PC) spectroscopy at 77 and 300 K, respectively.

A regular system of well shaped rectangular nanoislands (some kind of a "planch" structure) has been observed on the AFM scans (Fig. 1). The lateral dimensions of the islands are 100×300 nm; the height is about 10 nm. The islands are well ordered along the [110] direction, and are rather homogeneous in size.

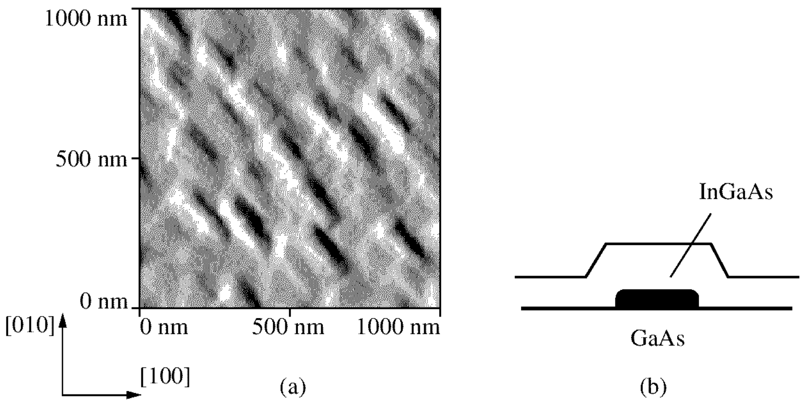

Fig. 1. AFM image of a planch structure (a) and suggested internal structure of a planch (b).

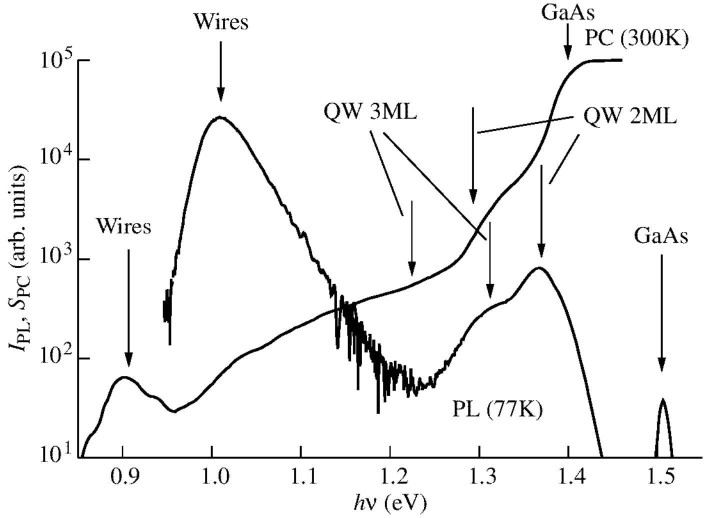

Fig. 2. The photoluminescence (77 K) and photosensitivity (300 K) spectra of a planch structure.

A strong PL line with a maximum at 1.01 eV (at 77 K) is seen in the PL spectrum (Fig. 2). The full width at half maximum of this peak is 55 meV. In the PC spectrum a corresponding photosensitivity peak with a maximum at $h\nu = 0.91$ eV is observed.

The most remarkable feature of the optical properties of this structure is strong polarization dependence both of the PL line and of the PC peak when the PL polarization in the direction perpendicular to the structure surface was analyzed or when the PC was excited by a beam polarized linearly perpendicular to the surface, respectively (Fig. 3). Maximum signal is observed when the electric field strength vector **E** in the emitted/incident light wave is parallel to the [110] direction on the structure surface, i.e. **E** is parallel to the longer axis of the planches. The degree of polarization $P = (I_{\max} - I_{\min})/(I_{\max} + I_{\min})$ equals 0.27 for PL and 0.25 for PC. Such polarization dependence allows to suggest existence of one-dimensional electronic states in these planches.

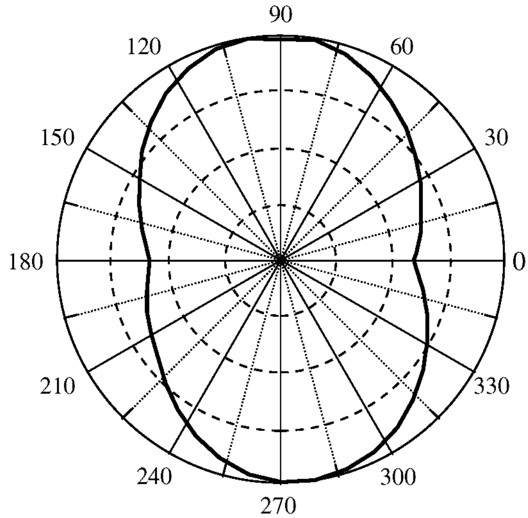

Fig. 3. Dependence of photosensitivity at $h\nu = 0.9$ eV (300 K) on the angle between the electric vector **E** in the incident linearly polarized beam and the [110] direction on the structure surface.

The two PL peaks at 1.4 and 1.3 eV were attributed to $In_xGa_{1-x}As$ quantum wells with $x = 0.9$ and the thickness equal to 2 and 3 monolayers (0.6 and 0.9 nm) respectively on the basis of comparing the calculated transition energies (using model [4]) with the experimental ones.

So far the inner structure of the planches can be suggested to be as shown on Fig. 1(b): plain InAs domains asymmetric in the $x-y$ plain substantially standing on an InGaAs wetting layer with large scale fluctuations in thickness by 1 monolayer. We have to suggest intermixing of In and Ga in the wetting layer since the observed spectral positions of the two QW peaks cannot be explained suggesting pure InAs wetting layer consisting of an integer number of monolayers.

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